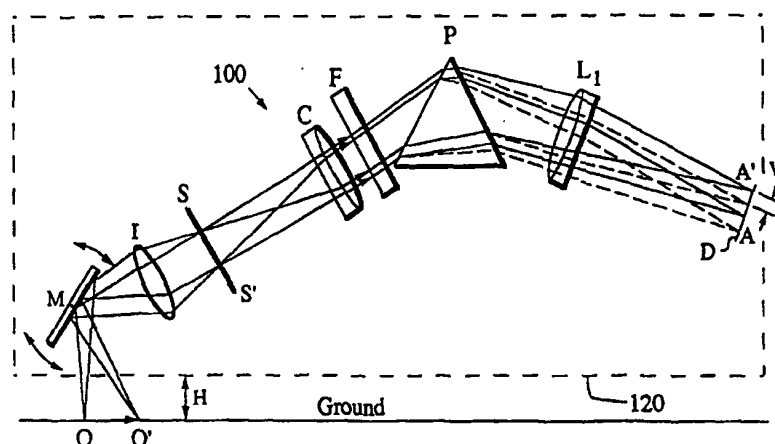




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: MULTI-SLIT IMAGING SPECTROMETER



## (57) Abstract

A multi-slit spectrometer is combined with a two-dimensional detector array (D) to enable simultaneous spectral analysis of several objects, improving the signal-to-noise ratio of multispectral imagery. The multi-slit spectrometer includes a multi-slit structure defining a plurality of parallel thin slits (S, S'), and a first lens (L) for directing object light onto the multi-slit structure. A second lens (C) collimates and directs light which has passed through the slits of the multi-slit structure onto a light dispersing element (P) such as a dispersing prism or a diffraction grating. A third lens (L<sub>1</sub>) focuses light which has passed through the light dispersing element onto the two-dimensional detector array at an image plane (A). A two-dimensional detector array (D) of detector elements is placed at the image plane. The slits are separated by a separation distance equal to an integral multiple of the detector width dimension, where the multiple is equal to (N times the number of slits) plus or minus one, where N is an integer. In an airborne sensor, a mirror (M) which rotates at an angular velocity related to the velocity of the airborne platform directs object light onto the first lens, freezing the image from one or more objects onto the multi-slit structure for an integration time.

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## MULTI-SLIT IMAGING SPECTROMETER

### TECHNICAL FIELD OF THE INVENTION

This invention relates to the field of spectrometry, and more particularly to a multi-slit spectrometer in combination with a two-dimensional detector array to enable  
5 simultaneous spectral analysis of several objects.

### BACKGROUND OF THE INVENTION

10 A spectrometer is used to analyze a beam of light into its component colors. FIG. 1 illustrates a simple prism spectrometer 10. Light from a luminous source I passes through a slit S and is collimated by lens C before impinging on the prism P. The index of refraction of the prism  
15 P varies as a function of wavelength. This is called dispersion. The index of refraction is greater for shorter wavelengths. Therefore, by Snell's law, the prism bends the violet light into a larger angle than the red light. Lens  $L_1$  focuses the light and forms a real image of the slit  
20 S at image plane A. The real image is called the spectrum of the luminous source I. The width W of the real image is a function of the maximum-minimum wavelength range of the luminous source I, the dispersion of prism P, and the focal length of lens  $L_1$ .

25 As shown in FIG. 1, the lateral location of the image of the slit S in the image plane A is a function of the

wavelength. If the light from luminous source I is monochromatic, i.e. a single wavelength (color), then only one image of the slit is formed. The color of the slit image is the color of the monochromatic light. If the light is  
5 polychromatic, i.e. white, then a continuum of slit images is formed, each at a slightly different location, and each at a slightly different color. In the example shown in FIG. 1, for example, the solid rays represent red light, and the dashed rays represent violet light.

10 It is well known that a thin straight slit is preferable to avoid overlapping of the images. If the slit is made wider, the purity of the slit images is reduced. In other words, at any point in image plane A, the image becomes a blend of slightly different wavelengths from the  
15 left, center and right side of the slit. This blending is the math function called convolution.

One application in which spectrometers are used is in obtaining aerial reconnaissance imagery, wherein the spectrometer is located on an aircraft, and a detector  
20 array is located at the image plane. Multispectral imagery is very low intensity because the spectrometer spreads the light received from objects on the ground across many detector elements.

## 25 SUMMARY OF THE INVENTION

A multi-slit spectrometer is described, and includes a multi-slit structure defining a plurality of thin slits, and  
30 a first lens for directing object light onto the multi-slit structure. A second lens collimates and directs light which has passed through the slits of the multi-slit structure onto a light dispersing element such as a dispersing prism or a diffraction grating. A third lens  
35 focuses light which has passed through the light dispersing

element onto the two-dimensional detector array at an image plane. In an airborne sensor, a mirror which rotates at an angular velocity related to the velocity of the airborne platform directs object light onto the first lens, freezing  
5 the image from one or more objects onto the multi-slit structure for an integration time.

The multi-slit spectrometer can be combined with a two-dimensional detector array such as a CCD camera or an infrared focal plane array to provide simultaneous spectral  
10 analysis of several objects. For applications such as aerial reconnaissance, this multi-slit feature results in longer integration times and hence higher signal-to-noise ratios. The detector array comprises a plurality of detector elements having a width dimension in a direction  
15 transverse to a direction in which the slits extend. The slits are separated by a distance equal to a multiple of the width dimension, wherein the multiple is equal to  $N$  times the number of slits, plus or minus one, where  $N$  is an integer.

20

#### BRIEF DESCRIPTION OF THE DRAWING

These and other features and advantages of the present invention will become more apparent from the following  
25 detailed description of an exemplary embodiment thereof, as illustrated in the accompanying drawings, in which:

FIG. 1 is a simplified schematic diagram of a conventional single-slit spectrometer.

FIG. 2 is a simplified schematic diagram of a multi-slit spectrometer in accordance with an aspect of this  
30 invention.

FIG. 3 illustrates a spectrometer system similar to the system of FIG. 2 except that a lens and a mirror are added in order to image a luminous (or illuminated) object  
35 on the ground.

FIG. 4A shows in simplified form an exemplary detector array suitable for use in the spectrometer of FIG. 2. FIG. 4B shows in enlarged view a small portion of the active area of the detector array of FIG. 4A, illustrating several  
5 of the individual elements.

FIG. 5 illustrates an exemplary multi-slit structure suitable for the spectrometer of FIG. 2.

FIG. 6 shows a diagrammatic side view of an exemplary eight slit spectrometer in accordance with an aspect of the  
10 invention.

FIG. 7 illustrates a multi-slit spectrometer system for visible/near IR (VNIR) radiation in accordance with the invention.

FIG. 8 illustrates a multi-slit spectrometer system embodying the invention, which is adapted for use in both  
15 VNIR and short wave infrared radiation (SWIR).

FIG. 9 is a simplified block diagram of a control system for a multi-slit spectrometer mounted on an airborne vehicle.  
20

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

One purpose of this invention is to improve the signal-to-noise ratio of multispectral aerial reconnaissance imagery. Multispectral imagery is very low intensity  
25 because the spectrometer spreads the light received from objects on the ground into a spectrum of length  $W$  in the image plane A of FIG. 1. The size of a detector element is  $D$ . The ratio of the spectrum length/detector element size  
30 ( $W/D$ ) is the number of spectral bands that can be detected by the spectrometer. Because the energy in the spectrum is spread over many detector elements, the energy falling on each detector element is greatly reduced. For example, if the number of spectral bands is 49, then the intensity of

the light falling on the detector element is 1/49th the level as compared to panchromatic imagery.

FIG. 2 illustrates a multi-slit spectrometer 50 in accordance with an aspect of this invention. The multi-slit spectrometer is similar to the single slit spectrometer of FIG. 1, except that a second luminous source I' and a second slit S' parallel to the first slit is added, along with a bandpass filter F. The slits S and S' are imaged onto the detector plane A, with a magnification equal to  $FL_{L1}/FL_C$ , where  $FL_{L1}$  and  $FL_C$  are the focal lengths of the respective lenses  $L_1$  and C. Note that the spectrum of luminous source I and luminous source I' are spatially separated in image plane A and A'. Thus, by adding a second slit, the prism spectroscope 50 may be used to simultaneously analyze the spectra from two luminous sources. The function of the bandpass filter F is to limit the maximum - minimum wavelength range of the luminous sources to the wavelength range of interest. Otherwise, the spectra from the two sources might overlap in image plane A. Typically a detector array will be located at the image plane. The length of each slit image should be at least equal to the length of the detector array, and the slit width, i.e. the slit dimension transverse to the longitudinal axis of the slit, is selected so that the slit opening image at the detector array is approximately equal to the width of the detector element.

FIG. 3 illustrates a spectrometer system 100, which is similar to the system of FIG. 2 except that a lens L and a rotatable mirror M are added in order to image a luminous (or illuminated) object such as an arrow O on the ground. The head of the arrow is imaged at slit S'. The foot of the arrow is imaged at slit S. For this example, it is assumed that the prism spectrometer 100 is installed on an unmanned airborne vehicle (UAV) 120 traveling at a velocity V and at an altitude H above the ground, and the slits

extend in a direction transverse to the direction of movement of the UAV. The mirror M rotates at angular velocity  $V_a$  in order to keep the image of the arrow O stationary on the slits S and S' for a period of time equal to the integration time of the detector array. Thus, the prism spectrometer 100 can simultaneously analyze the spectra of the head and foot of the arrow.

A two-dimensional detector array D is located in image plane A-A'. The detector array D may be, for example, a CCD camera for the visible and near infrared (VNIR) or a focal plane array (FPA) for the infrared. FIG. 4A shows in simplified form an exemplary detector array D, including an active area 12. The active array area includes small detector elements arranged in rows and columns, with the rows extending in directions parallel to the slits. The detector elements are the individual, discrete sensors in the detector array. Each element is independent (isolated) from its neighbors and outputs electrical current in proportion to the number of photons incident on its top surface. By way of example only, one detector array suitable for the function has an active detector array area which is 7.84 mm by 12.8 mm, and each detector element is 20 microns by 20 microns. FIG. 4B shows in enlarged view a small portion of the active area 12, illustrating several of the individual elements 14. The width of the detectors in the CCD or FPA is ideally the same as the width of the image of the slits. The number of detectors onto which the spectrum falls is the number of bands. Thus, for example, if the number of detectors in the direction of the spectrum spread is 392, and the number of slits is 8, the number of bands is  $392/8$ , or 49 bands. The change in wavelength across a detector is the spectral width of each band. For a typical prism spectrometer, the spectrum is from 1000 - 2500 nanometers. Thus the spectral width of each band, in this example, is  $(2500 - 1000)/49 = 30.612$  nanometers. The



physical width of the spectrum in image plane A-A' of this exemplary embodiment is 980 microns. The number of detectors is 49 and the size of the detectors is 20 microns.

5 A spectrometer reduces the energy on the detector by a factor of  $1/(\text{number of bands})$ . In the above example, the number of bands is 49. Thus, the energy on a detector is  $1/49$  of the magnitude of the energy received at the slit (assuming no losses in the optics). This results in lower signal-to-noise ratios which might be compensated by longer  
10 detector integration times.

The integration time is limited because the UAV is moving at velocity  $V$ . For continuous spectral analysis of terrain at a ground resolution  $R$ , the maximum integration time using a single slit is  $R/V$ . For a typical mission,  $V$   
15  $= 56$  meters per second and  $R = .665$  meters. Therefore, the maximum integration time using a single slit is  $.665/56 = 11.88$  milliseconds. After 11.88 milliseconds, the next .665 meter wide ground swath must be imaged onto the slit  $S$ . Otherwise, there will be gaps in the terrain measurements.  
20

The solution is to use multiple parallel slits and a two dimensional detector array to increase the integration time. For example, assume the spectrometer includes a slit structure with eight parallel slits. FIG. 5 illustrates an  
25 exemplary slit structure 20. This structure 20 is 11 mm (height) by 17 mm (length). The structure 20 has defined therein 8 parallel slits 22A-22H, each of which is 0.02 mm wide and 12.8 mm long. The slits are separated by a distance of 0.98 mm.

30 Since there are 49 spectral bands, the two-dimensional detector array corresponding to the slit structure 20 should have  $49 \times 8 = 392$  detector element rows. The energy through slit 22A is spread over detector rows 1-49, the energy through slit 22B is spread over rows 50-98, and so  
35 on, with the energy through slit 22H spread over rows 344-

392. Because the prism spectrometer is simultaneously looking at eight swaths on the ground, the integration time is eight times longer ( $8 \times 11.88 \text{ msec} = 95 \text{ msec}$ ). Therefore, the illuminance level needed for the eight slit spectrometer is only  $1/8$  as bright as needed for the single slit prism spectrometer. This is important for flying missions on dark and overcast days late in the afternoon or early in the morning under twilight conditions.

FIG. 6 shows a diagrammatic side view of an exemplary eight slit spectrometer 150 in accordance with an aspect of the invention. The system uses an 8 slit structure 20 as shown in FIG. 5, with slits 22A-22H. The numbering of the ground pixels imaged onto each slit is shown at the bottom of the figure for time periods 1 - 4. The rotatable backscan mirror M freezes the image of the ground onto the slits during the detector integration time. At the end of the integration time, the backscan mirror quickly resets to its original angle and starts the next backscan at time 2 (time 1 + 95 msec). Note that the image of the ground onto the slits has been shifted by exactly 8 ground pixels because the UAV travels 8 ground pixels in 95 msec ( $56 \text{ meters/sec} \times 95 \text{ msec} = 5.32 \text{ meters} / 8 \text{ ground pixels} = .665 \text{ meters per ground pixel}$ ). This shift of 8 ground pixels is repeated every subsequent time period.

There will be no gaps in the reconnaissance of the terrain if the spacing of the slits (in detector element width units) is one more (or one less) than the modulo number of slits. Thus, the spacing of the slits will be equal to N times the number of the slits plus 1, times the detector element width, where N can be any integer number 1, 2, ... N. For the example shown in FIG. 6, modulo = 6. Modulo  $\times$  number of slits =  $6 \times 8 + 1 = 49$ . The slit spacing, for a detector width of 20 microns, will be 980 microns.

Table A shows the progression of filling in all the ground pixels in 49 time periods. By way of example, ground pixel 392 is imaged through slit A during time period 7, ground pixel 391 is imaged through slit B at time period 13, and so on.

TABLE A

	Time	H	G	F	E	D	C	B	A
	1	1	50	99	148	197	246	295	344
	2	9	58	107	156	205	254	303	352
10	3	17	66	115	164	213	262	311	360
	4	25	74	123	172	221	270	319	368
	5	33	82	131	180	229	278	327	376
	6	41	90	139	188	237	286	335	384
	7	49	98	147	196	245	294	343	392
15	8	57	106	155	204	253	302	351	400
	9	65	114	163	212	261	310	359	408
	10	73	122	171	220	269	318	367	416
	11	81	130	179	228	277	326	375	424
	12	89	138	187	236	285	334	383	432
20	13	97	146	195	244	293	342	391	440
	14	105	154	203	252	301	350	399	448
	15	113	162	211	260	309	358	407	456
	16	121	170	219	268	317	366	415	464
	17	129	178	227	276	325	374	423	472
25	18	137	186	235	284	333	382	431	480
	19	145	194	243	292	341	390	439	488
	20	153	202	251	300	349	398	447	496
	21	161	210	259	308	357	406	455	504
	22	169	218	267	316	365	414	463	512
30	23	177	226	275	324	373	422	471	520
	24	185	234	283	332	381	430	479	528
	25	193	242	291	340	389	438	487	536
	26	201	250	299	348	397	446	495	544
	27	209	258	307	356	405	454	503	552
35	28	217	266	315	364	413	462	511	560
	29	225	274	323	372	421	470	519	568
	30	233	282	331	380	429	478	527	576
	31	241	290	339	388	437	486	535	584
	32	249	298	347	396	445	494	543	592
40	33	257	306	355	404	453	502	551	600
	34	265	314	363	412	461	510	559	608
	35	273	322	371	420	469	518	567	616
	36	281	330	379	428	477	526	575	624
	37	289	338	387	436	485	534	583	632
45	38	297	346	395	444	493	542	591	640
	39	305	354	403	452	501	550	599	648
	40	313	362	411	460	509	558	607	656
	41	321	370	419	468	517	566	615	664
	42	329	378	427	476	525	574	623	672

	43	337	386	435	484	533	582	631	680
	44	345	394	443	492	541	590	639	688
	45	353	402	451	500	549	598	647	696
	46	361	410	459	508	557	606	655	704
5	47	369	418	467	516	565	614	663	712
	48	377	426	475	524	573	622	671	720
	49	385	434	483	532	581	630	679	728
	50	393	442	491	540	589	638	687	736
	51	401	450	499	548	597	646	695	744
10	52	409	458	507	556	605	654	703	752

Many other combinations of modulo and number of slits are possible. However, the rule stated above must be followed in order to preclude having gaps in the reconnaissance of the terrain. If the rule is not followed, the scanning mirror angular scans will not be equal. The scanning mirror will have to periodically make a large scan in order to avoid having gaps. Also, the detector array time-off will increase.

FIG. 7 illustrates a multi-slit spectrometer system 200 for visible/near IR (VNIR) radiation, in the range of 0.4 micron to 1 micron, that also simultaneously functions as an SWIR imager. The reflective relayed imager 202 is generally the final optical assembly for the nominal staring sensor; the system 200 uses a rotatable mirror 203 to freeze the image of the ground for the integration period. The imager 202 in this example includes reflectors 204, 206, 208, 210, and provides the cold shielding required for operation of a cryogenically cooled IR detector focal plane array (FPA) 212. Of course, it will be recognized that the optical path to the FPA is not a spectrometer, but rather is a conventional imager. A dichroic beamsplitter 214 is inserted into the optical path of imager 202 immediately before the cryo-vac dewar window 216. Radiation with wavelengths shorter than those sensed by the IR focal plane array (FPA) 212 are split from the optical path by the beamsplitter 214 and are sent to the multi-slit structure 218 at the focus of imager 202 and

then to the reflective triplet collimator 220. Collimator 220 in this example includes reflectors 222, 224 and 226. The collimator 220 receives radiation from the image formed by imager 202 and collimates it prior to spectral dispersion by the prism element 228. After the prism, the radiation is imaged onto a two dimensional detector array 230 such as a back illuminated charge coupled device (BCCD) by imager 232, which can be an identical copy of the optics used in collimator 220 if the detector array 230 used does not require cooling.

It is to be noted that the particular number of slits in the multi-slit structure will be dependent on the requirements of specific applications, and so an 8 slit structure is merely exemplary. In general, for applications requiring high spectral resolution, a multi-slit structure can be employed with fewer than 8 slits and larger spacing between slits, and a highly dispersive prism used. For applications where lower spectral resolution is needed, a slit structure with more than 8 slits (with closer spacing) can be employed, and a less dispersive prism is used such that the desired spectrum from each slit is dispersed over only a portion of the detector array. In this manner, the images of one slit formed by the shortest to the longest wavelength is immediately adjacent to the images of the next slit on the detector array. It should be noted that in the system 200 of FIG. 7, longer wavelength radiation can still be passed through the dichroic beamsplitter 214 into the cryo-vac dewar for detection by a cooled IR FPA.

FIG. 8 illustrates a multi-slit spectrometer system 250 adapted for use in both VNIR (0.4 - 1 micron) and SWIR (1 - 2.5 micron). In the system 250 of FIG. 8, no beamsplitter is employed in imager 202, and the cooled IR detector array 212 is removed from the focus of imager 202. All radiation is passed through a slit structure 252

located at the focus of imager 202 and is collimated by the reflective triplet collimator 220.

In the collimated region following collimator 220, a dichroic beamsplitter 254 is used to divide the radiation into two parts. The shorter wavelengths are reflected by the beamsplitter 254 and pass through a dispersing prism 256 for imaging onto a room temperature array (BCCD) by imager 232. As in the system 200 of FIG. 5, imager 232 can be an identical copy of the optics used in collimator 220. The longer wavelengths are transmitted by the beamsplitter 254 and pass through another dispersing prism 258 for imaging onto a cryogenically cooled detector array 212 by imager 260.

Imager 260 includes reflectors 262, 264, 266 and 268, and can be an identical copy of imager 202, since it has the required relayed optical form to provide cold shielding.

The systems shown in FIGS. 7 and 8 are adapted to use in airborne applications. Other embodiments of the invention can be used for mid-wave IR (MWIR) and long-wave IR (LWIR) applications. The multi-slit spectrometer has utility for wavelengths between 0.4 microns and 12 microns.

FIG. 9 is a simplified block diagram of the control system for a multi-slit spectrometer mounted for use on an airborne vehicle such as a UAV. The system includes a controller 300, which can be a microprocessor-based CPU, programmed with appropriate instructions to convert UAV speed and altitude data provided by UAV sensors 302 into mirror actuation commands and detector array control signals. The system also includes a mirror actuator 304 for moving the mirror M through a range of motion to hold the ground image stationary during an integration time. The controller 300 may include programming to compute the integration time based on the speed and altitude, and to

control the detector array D, by an integration time command, to use this integration time.

The invention is applicable to systems operating in scanning mode as well as systems which operate in staring mode. A conventional scanning mode of operation of a  
5 conventional spectrometer occurs when the image of the ground is imaged on a slit S and there is no backscan mirror (or it is turned off). Thus, the invention can be employed in scanning mode by fixing the position of the  
10 mirror, or by removing the mirror. Of course, if the mirror is fixed, the ground image is convolved with the slit width, reducing resolution, and the integration time will be no longer than the integration time using a single slit. With a fixed mirror, the detector must be turned off  
15 for most of the time, i.e. the time-off fraction = (number of slits minus one)/(number of slits).

It is understood that the above-described embodiments are merely illustrative of the possible specific embodiments which may represent principles of the present inven-  
20 tion. For example, the invention has been described above for use with a dispersive prism, but a diffraction grating may be used in place of the dispersive prism. Other arrangements may readily be devised in accordance with these principles by those skilled in the art without  
25 departing from the scope and spirit of the invention.

CLAIMSWhat is claimed is:

1. A multi-slit spectrometer, characterized by:  
a multi-slit structure defining a plurality of parallel thin slits (S, S');  
a first optical structure (L) for directing object  
5 light onto said multi-slit structure;  
a light dispersing element (P);  
an optical collimating device (C) for collimating and directing light which has passed through said slits of said multi-slit structure onto said light dispersing element;  
10 and  
an optical focusing structure (L<sub>1</sub>) for focusing light which has passed through said light dispersing element at an image plane (A, A').
2. A spectrometer according to Claim 1 further characterized by a two-dimensional detector array (D) disposed at said image plane.
3. A spectrometer according to Claim 1 or Claim 2, further characterized in that said detector array (D) comprises a plurality of detector elements having a width dimension in a direction transverse to a direction in which  
5 the slits extend, and wherein said slits (S, S') are separated by a distance equal to an integral multiple of said width dimension, wherein said integral multiple is equal to (N times the number of slits) plus or minus one, where N is an integer.
4. A spectrometer according to any preceding claim, further characterized in that said light dispersing element (P) includes a prism.



5. A spectrometer according to any of Claims 1-3, further characterized in that said light dispersing element (P) includes a diffraction grating.

6. A spectrometer according to any preceding claim, further characterized by a filter (F) for passing only light in a wavelength band of interest, said filter positioned in the optical path before the image plane.

7. A spectrometer according to any preceding claim, further characterized in that said spectrometer is mounted on a moving platform, and further comprising a mirror (M) for directing object light from one or more objects onto  
5 said first lens, said mirror rotating at an angular velocity to keep the image of said one or more objects stationary at said multi-slit structure for an integration time.

8. A spectrometer according to Claim 7, further characterized by a mirror actuator (304) for moving the mirror in response to mirror actuation commands, and a controller (300) responsive to data indicative of the speed  
5 and altitude of the for generating said mirror actuation commands to rotate said mirror at said angular velocity.

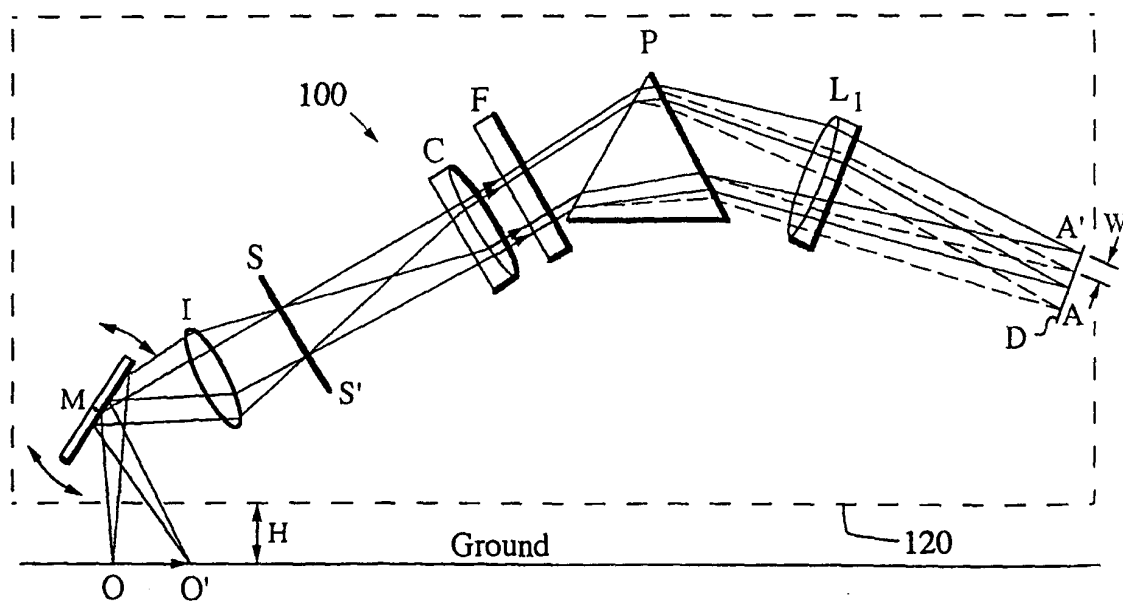
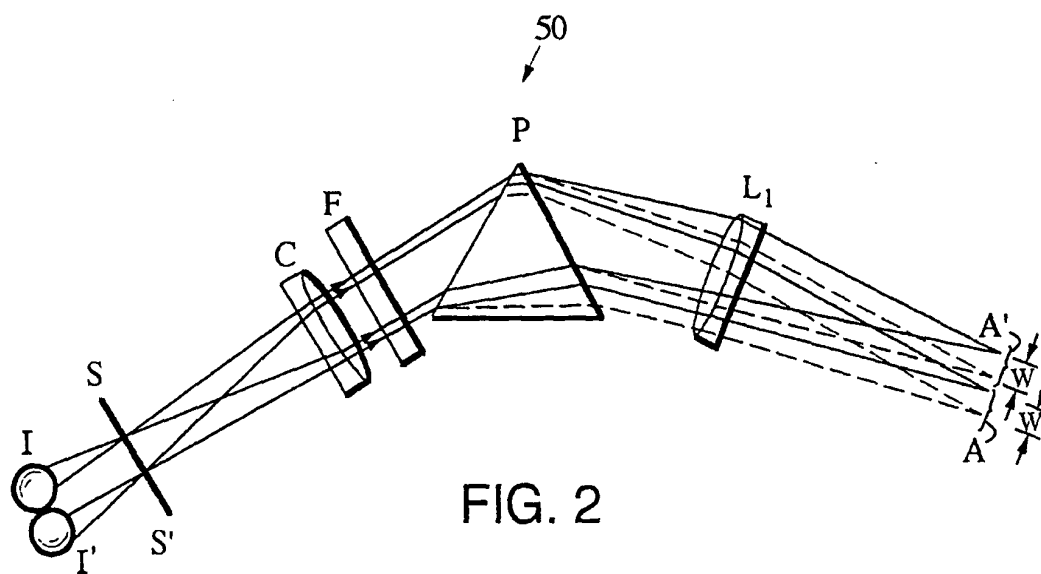
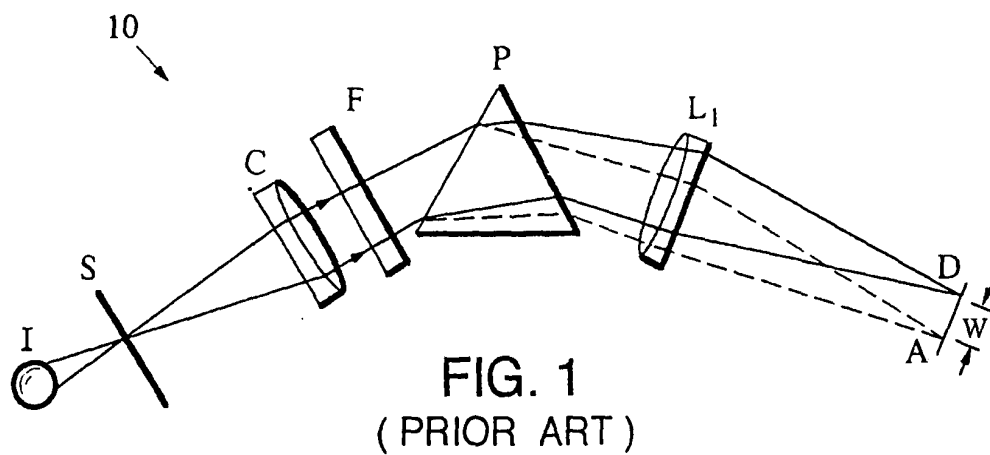
9. A spectrometer according to any preceding claim, further characterized in that the spectrometer is used in a system (200) for analyzing input energy in first and second different spectral bands, the system including a  
5 first optical structure (202) for directing said input energy onto a beam splitter (214), said beam splitter for directing first spectral band components of said input energy through a first optical path to a first sensor array (212) and for directing second spectral band components of  
10 said input energy to a second optical path, the spectrom-

eter disposed in said second optical path for analyzing said second spectral band components.

10. A spectrometer according to Claim 9, further characterized in that said first spectral band is in the near infrared, and said first sensor array (212) is a cryogenically cooled array.

11. A spectrometer according to any of Claims 1-8, further characterized in that the spectrometer is used in a system (250) for analyzing input energy in first and second different spectral bands, the system including a first optical structure (202) for directing input energy onto said multi-slit structure (252), a collimator (220) for collimating light which has passed through the multi-slit structure, a beam splitter (254) for directing components of said input energy in a first energy band to a first optical path, and for directing components of said input energy in a second spectral band to a second optical path, a first light dispersing element (258) disposed in the first optical path, a second optical structure (260) for imaging light which has passed through the first light dispersing element onto a first image plane, a second light dispersing element (256) disposed in the second optical path, and a third optical structure (232) for imaging energy which has passed through the second light dispersing element onto a second image plane.

12. A spectrometer according to Claim 11 further characterized in that said first spectral band includes visible and near infrared spectral components, and said second spectral band includes short wave infrared components.



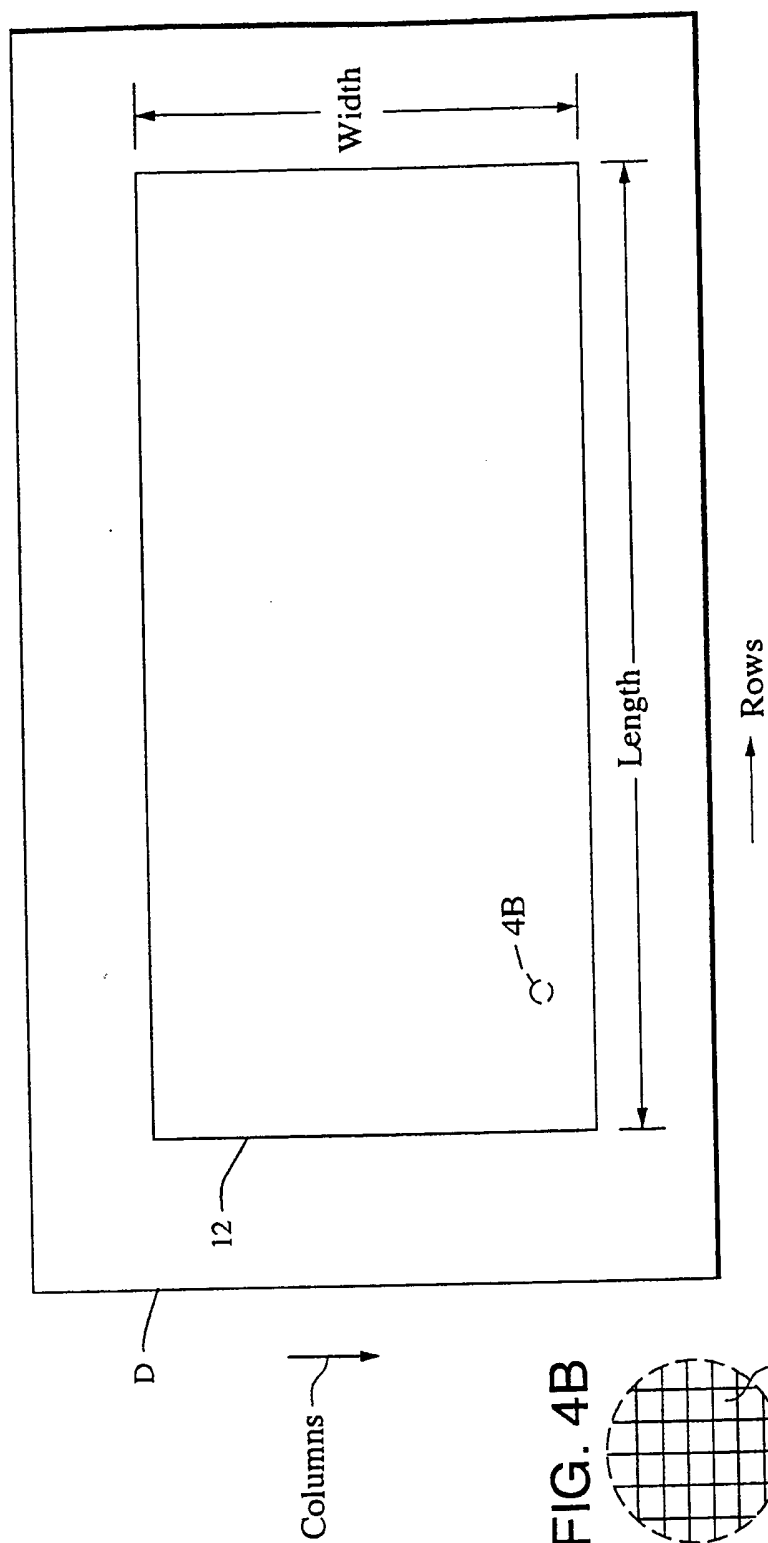
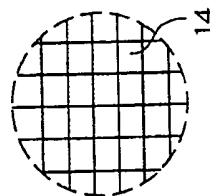


FIG. 4A

FIG. 4B



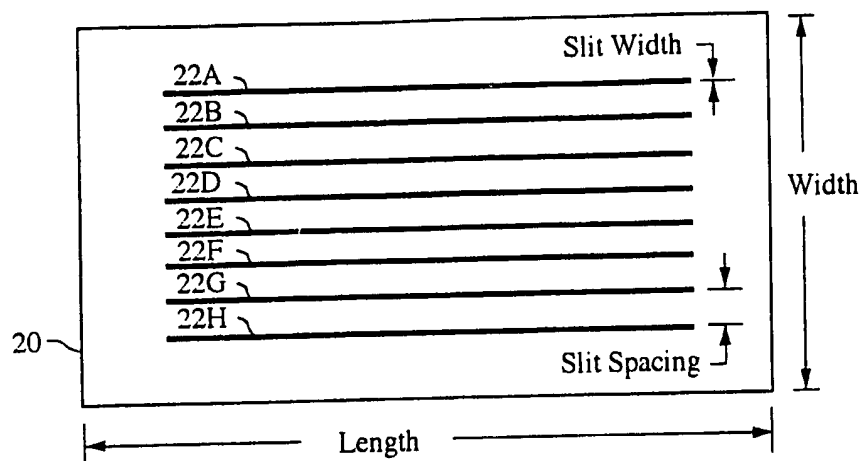
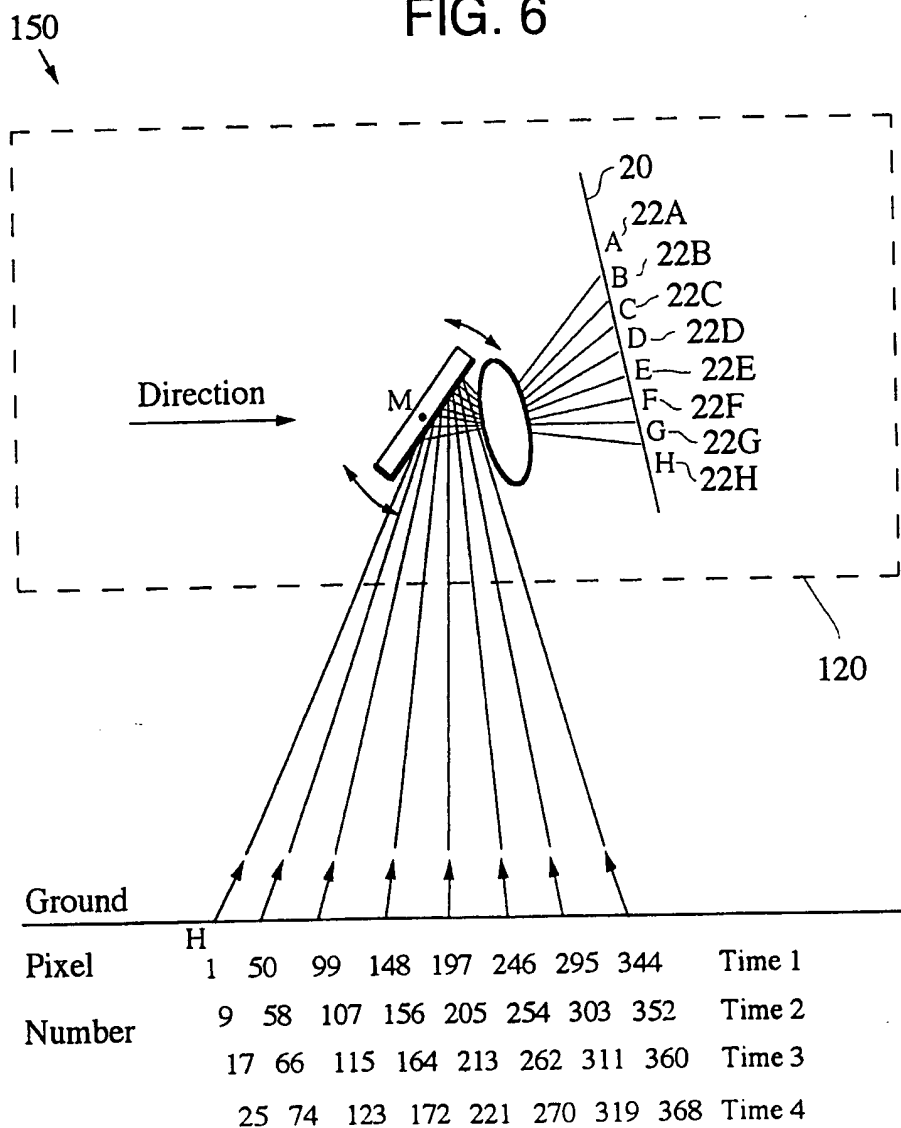


FIG. 5

FIG. 6



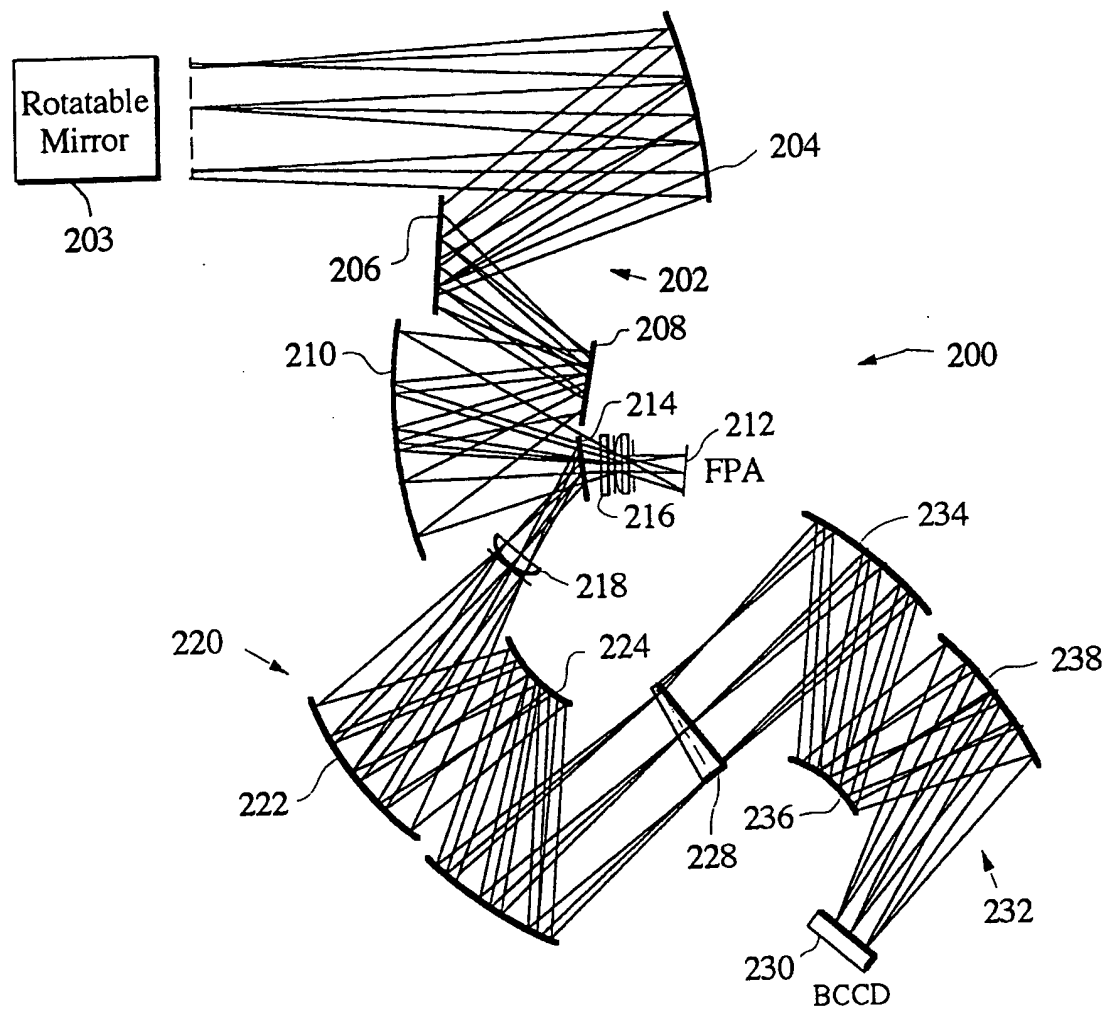


FIG. 7

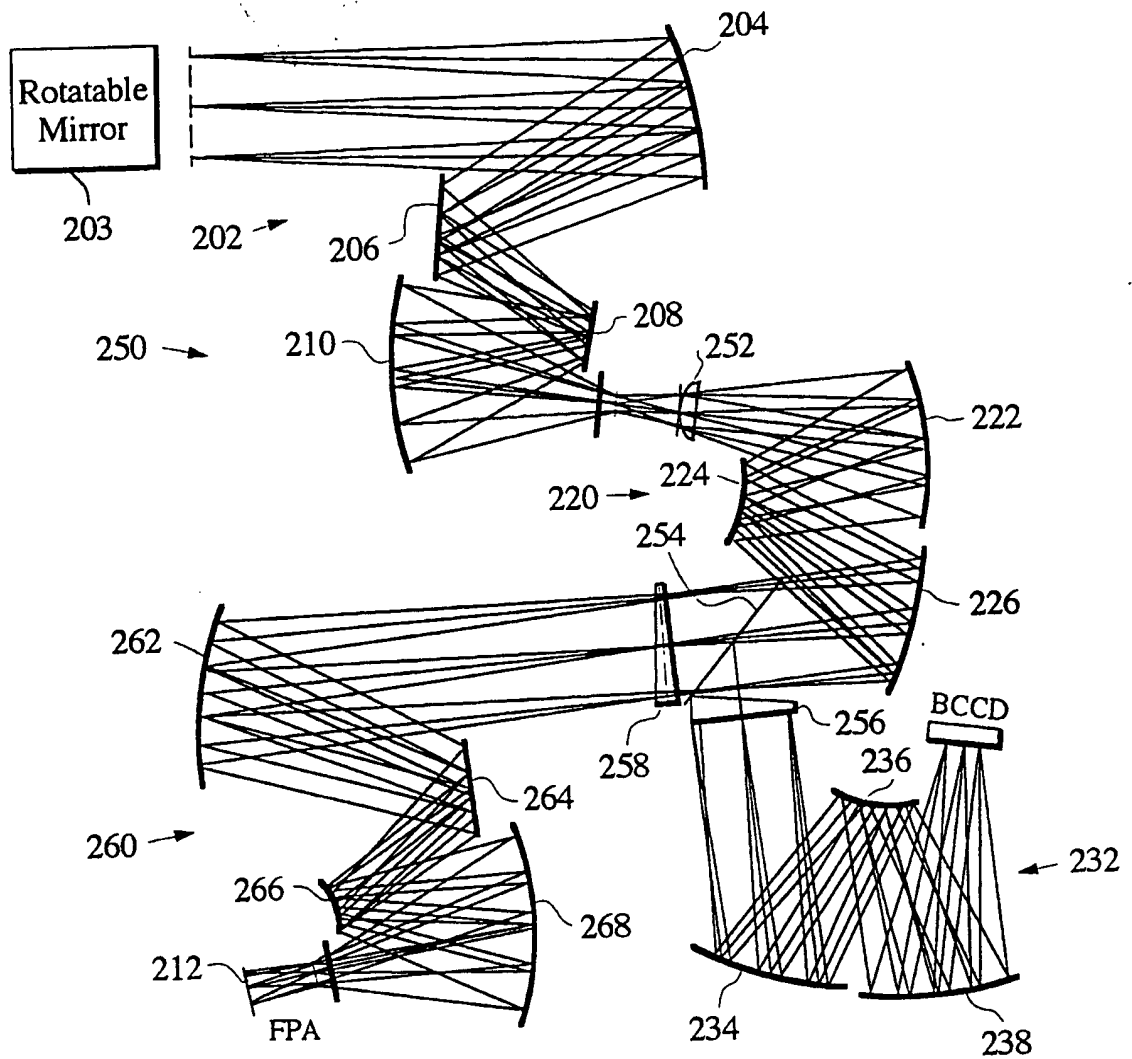
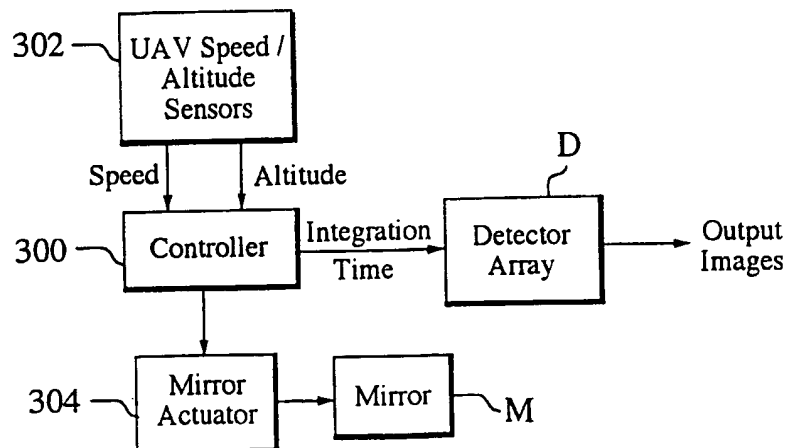


FIG. 8

FIG. 9



PCT/US 99/10154

IPC 6 G01J3/28

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 6      G01J      G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 5 627 639 A (MENDE STEPHEN B ET AL) 6 May 1997 (1997-05-06)	1,2,5
Y	column 1, line 11 - line 14 column 1, line 33 - line 36 column 1, line 39 - line 56 column 3, line 10 - line 29 column 4, line 37 - line 61 column 5, line 19 - line 28 figures 1,2 ---	3,4,6-12
Y	EP 0 642 005 A (THOMSON CSF) 8 March 1995 (1995-03-08) column 1, line 1 - line 11 column 1, line 49 - column 2, line 16 column 2, line 47 - column 3, line 22 column 7, line 15 - line 43 figures 1,7 ---	3,4

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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

14 July 1999

Date of mailing of the international search report

21/07/1999

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# INTERNATIONAL SEARCH REPORT

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